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Industrial Ecology and Life Cycle Assessment

What's the Use?

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Introduction

Life Cycle Assessment (LCA) and industrial ecology came of age at roughly the same time. LCA and the related endeavors of life-cycle management and integrated product policy are crucial components of industrial ecology. Life-cycle thinking is one of the principal means by which industrial ecology attempts to realize its goal of taking a systems view of environmental problems and remedies.

This brief paper discusses a central issue confronting LCA and industrial ecology: how can robust conclusions be drawn from the last 15 years of the use of LCA and allied tools? Can the industrial ecology community generate any insights that go beyond either the heuristics that were already commonplace in the environmental arena by the 1990s – avoid toxic substances, use renewable materials, minimize energy use, encourage recycling, etc. – on the one hand, or the familiar answer refrain that seems to be the result of so many LCAs, "it depends…".

Industrial Ecology and Life Cycle Assessment

Industrial ecology is a field that emerged in the early 1990s. Its self-conscious existence is typically dated to a seminal publication, 'Strategies for Manufacturing'(Frosch and Gallopoulos 1989) that articulated a vision of a more environmentally benign future based in part on the design or arrangement of industry drawing on insights from natural systems and subsequently became labeled as the biological analogy. To some, this notion that industry can or should emulate the efficiency of resource utilization found in nature is the hallmark of industrial ecology. To others, the term industrial ecology refers to byproduct exchanges and resource sharing enabled by geographic proximity exemplified by the dense web of exchanges in the industrial district in Kalundborg, Denmark (Ehrenfeld and Gertler 1997, Jacobsen 2006). However, the concepts and literature of industrial ecology are broader than the biological analogy or by-product exchange (Lifset and Graedel 2002).

There are many definitions of industrial ecology. The *Journal of Industrial Ecology* defines the field as one which systematically examines local regional, and global uses and flows of materials and energy in products processes, industrial sectors, and economies. It focuses on the potential role of industry in reducing environmental burdens throughout the product lifecycle.

Thus industrial ecology has (at least) two clear connections to LCA: it examines the flow of materials and energy that constitute the core of life-cycle inventories, and it employs the cradle-to-grave framework as a central means of pursuing a systems approach to environmental analysis and decision making.

The Problem

As with all assessment tools, LCA faces the tension between speed, cost and intelligibility on the one hand and comprehensiveness and rigor on the other. The decision maker's need for simple, quick answers has led to a variety of approaches to rapid, low cost assessment, both in the form of various types of streamlined life-cycle assessment (SLCA, see Christiansen 1997, Todd and Curran 1999) and in a multitude of software tools.[1] Graedel, a proponent of streamlined approaches, argues that perhaps 80% of the insights to be gained from LCA can be obtained using SLCA (Graedel 1998). If so, the question then becomes: where is the dividing line between the 80% easily grasped through expedited approaches and the more complicated, remaining 20%? Some efforts to delineate this boundary are beginning to emerge (Hochschorner and Finnveden 2003, Hur et al. 2005). Input-output LCA (Hendrickson et al. 1998) and hybrid IO-process LCA (Suh et al. 2004) clearly represent an important path for grappling with these questions. As input-output analysis is incorporated into commercial LCA software, the prospects for this improve further.

[1] For a compilation of LCA software tools, see the U.S. EPA's list at <http://www.epa.gov/ORD/NRMRL/lcaccess/resources.htm#Software>

More broadly, can researchers look back on a decade and a half of research and identify patterns? For example,

- Which life cycle stages account for the greatest impacts? Does this correlate with product categories (durables, packaging, electronics, etc.)?
- When are proxies such as energy or mass reliable indicators of the larger set of environmental themes of interest to decision makers (Udo de Haes 2006)? Under what circumstances do they mislead?
- When are recycling and other forms of loop closing environmentally beneficial?
- Under what circumstances can one material be seen as environmentally preferable to its competitors?

Any thoughtful researcher will point out that the inferences to be drawn from an LCA depend on the questions that motivated it – in LCA lingo, this is at the heart of scoping. While this is true of most modeling endeavors, it is especially the case in LCA and other modeling where the results are highly sensitive to how system boundaries are drawn.

The contingent nature of the answers provided by LCA is exacerbated by the cultural and institutional norms faced by scientists as they are often leery of generalizing beyond the results of their work. In addition, a study is bound to attract more attention if it overturns conventional wisdom. There is less professional acclaim to be gained by carefully confirming prevailing notions or even incrementally advancing the quantitative understanding of patterns in the field.

Further, the task itself is daunting. For example, it has long been argued that for products that consume energy when in service, environmental impacts in the use phase dominate. Yet, Williams and colleagues (Williams 2004, Williams et al. 2002) have fundamentally challenged that generalization by arguing that the consumption of materials and energy in the life cycle of microchips occurs disproportionately in the production phase, rather than the use phase. This raises the possibility that many electronic products – indeed a vast number of electrical products as microchips become ubiquitous in goods other than computers – will have their primary impact in production rather than consumption.

The Solutions?

Insight into patterns could be gained by compiling a catalogue or library of life-cycle studies. The Dutch consulting firm and author of the well-known LCA software, SimaPro, has created a free online library called 'The LCA Search Tool' <http://www.pre.nl/LCAsearch/default.htm>. Task Force 4 of the Life Cycle Inventory Program within the UNEP/SETAC Life-cycle Initiative is considering the creation of a Life Cycle Case Studies library.

Other such libraries exist in related fields. For example, the Harvard Center for Risk Analysis and the Harvard School of Public Health maintain the Cost Effectiveness Analysis (CEA) Registry <www.hsph.harvard.edu/cearegistry/>. The Cost Benefit Group (CBG), formerly Damage Valuation Associates, a consulting firm that specializes in evaluating the economic and financial impacts of environmental hazards and real estate development projects, publishes the Newsletter *Environmental Valuation & Cost-Benefit News* and maintains an associated on-line index of studies that ascribe monetary values to environmental benefits and damages <http://envirovaluation.org/>.

Such catalogues, while enormously useful for a variety of purposes, will not by themselves allow inferences about cross-cutting patterns because of the obvious incompatibility of the scope and design of the various studies. Systematic and careful meta-analysis, such as the comparison of LCAs of biopolymers and bioenergy by Dornburg et al. (2003), can generate reliable inferences. Such studies are, of course, complicated and time-consuming, and crucially dependent on whether the underlying studies can actually be adjusted to make them commensurate, but some efforts are being made (Hanssen 1998, Sun et al. 2004, Daniel et al. 2004, Rydh and Sun 2005). Early proposals for the UNEP/SETAC Life Cycle Library called for meta-analyses as part of the project scope, though this makes some stakeholders nervous. They fear that the conclusions drawn could put them to a disadvantage in the market or in policy deliberations. Even if such meta-analyses are not part of the Library project itself, however, they can be facilitated by the design of the library and by subsequent funding by research sponsors that builds on this or other case libraries.

Another approach is to design research specifically to attack these questions. David Allen of the University of Texas, a pioneer in industrial ecology, has suggested that 'test beds' be created that would allow evaluation of various tools to facilitate our collective understanding of how tools differed in their strengths, biases, and orientation. (To my knowledge, that suggestion has never been taken up.) An analogous approach could be used to investigate patterns in *results* of LCAs: Create a series of consistent cases that vary explicitly along dimensions of interest – materials choice, end of life treatment – and evaluate those cases using a variety of prominent LCA models. This is in part what Hanssen (1998) did in the study cited above of product groups.

Yet another strategy would be to build on related scientific knowledge. One approach, mentioned above, is linking with input-output analysis as in hybrid LCA. Another builds on preliminary work on the use of artificial intelligence to detect patterns in product life cycles (Sousa et al. 2000, Ryan 2004, Park et al. 2002). Sousa and colleagues (2000), for example, outline an approach that uses neural networks to find correlations between product attributes and life-cycle inventories.

Implications

The sophistication of LCA, and of environmental systems analysis more generally, have grown enormously in the past decade and a half. The science is more developed, the con-

nections to decision theory are better articulated[2], data have improved and, most conspicuously, standards have been established. Yet, it is not clear that the experts can tell decision makers and users more in the way of generic guidance than could be offered in the beginning of the 1990s.

The challenges and limitations of LCA often lead to a focus on tool development, both because the tools are needed and because making generalizations based on LCAs is daunting. Yet, if the goals of industrial ecology are to understand and to improve environmental performance, there must be a commensurate effort to generate knowledge as well as technique. It may turn out that useful generalizations are truly few and far between, but the effort to delineate them will nonetheless teach us a great deal about the world we seek to understand the frameworks we currently use to do so.

[2] See, for example, Seppälä et al. 2001, Rahimi and Weidner 2004a, 2004b.

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